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An Investigation of Structural Effects due to Utility Openings on Performance of Steel Hollow Poles

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ABSTRACT

Hollow circular utility poles are widely used for various applications such as smart poles, street lighting poles, traffic single poles, etc. The provision of openings in these poles are essential for operational and maintenance requirements. Provisions of two openings are also needed in certain cases such as smart poles due to safety and other operational concerns. However, these openings could cause increase in stresses in the regions where these openings are introduced inducing local buckling and other structural concerns. This study focusses on reduction of local buckling capacities of hollow circular poles with dual service openings and the effect of variation of width and depth of openings on it. Two smart poles having nominal height of 20m and 24m was considered in this study and the effect on local buckling by these opening was modelled through 3D finite element modelling. According to the results of analyses, buckling capacities of hollow circular poles were drastically affected by the introduction of dual openings. In most of the cases, poles exceeded the buckling capacities with introduction of utility opening unless some form of strengthening was not introduced for the critical region. Further, increase in the width of openings is greatly affected on buckling capacity than increase in height of openings.

Keywords: Hollow circular utility poles, Local buckling, Smart poles, Utility openings sensor

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1. INTRODUCTION

Utility steel hollow poles play an important role in modern infrastructure as supporting structures for lighting fixtures, traffic signals, security cameras, and other various applications. Unlike concrete or wood, steel offers distinct advantages in terms of strength, easy maintenance, and cost-effectiveness, making it ideal for this type of structural applications. With the recent technological development, the smart pole concept has emerged as a modern urban infrastructure solution. Smart pole is an integrated steel structure

designed mainly for installation of telecommunication network components, which includes 4G/5G antennas, while providing provisions for many other services. Generally, these smart poles provide services such as street lighting, surveillance with CCTV cameras, digital information screens, charging stations, etc in addition to facilitating telecommunication services. Sri Lanka's mobile broadband subscriptions increased by 24.7% in 2020-21 and showed consistent growth over time in recent years recording

20.6 Million subscriptions by 2024, reflecting high internet demand according to TRCSL Telecom Statistics Q4 2024 [1]. To meet high-speed internet demand, service providers gradually shift towards 5G technology. For the deployment of 5G technology, compacted towers are required at closer spacing especially in urban areas. Hence, smart poles are commonly being used by telecommunication service providers in Sri Lanka in recent years, mainly in this regard while providing other integrated services through same pole.

Openings of hollow circular utility & smart poles are essential as service cables for antennas, streetlamps, display units, etc are provided through cable racks

fixed inside the hollow space of the pole. Usually, data cables and power cables are not fixed in same cable racks due to interference and safety concerns. Therefore, two sets of cable racks are fixed at two opposite ends of hollow poles with two utility openings at those two sides close to the ground level for operational and maintenance requirements. However, introduction of these types of utility openings may become a structural concern as stress concentrations at corners of those openings could lead to local buckling and other stress related concerns in these regions of poles. Figure 1 shows a smart pole and its utility openings at two opposite sides.



Figure 1. A smart pole and its utility openings at two opposite sides

Various studies have been conducted to investigate the effects of openings on utility poles and other structural elements. A study conducted by Eui Lee et al 2016 [2] investigated effects on ultimate strength of cylindrical shells with cutouts. This study focuses on the effects of cutouts on the ultimate strength of cylindrical shells, especially in wind turbine towers. The study proposes a formula to predict the reduction in strength of cylindrical shells subjected to axial compression and pure bending loads using finite element analysis. The outcomes revealed that the ultimate strength of cylindrical shells reduces with the provision of cutouts, and reduction of the strength depends on the shape and the location of the cutout. Rectangular openings showed a 20% of strength reduction, reporting the highest reduction. A research by De'nan et al 2024 [3], on tapered steel beam sections with openings showed that, subjected to bending showed that the yield moment and ultimate

moment are considerably reduced with the provision of openings. A significant reduction in structural capacity has been reported when the number of openings is increased. It has further proposed a methodology to minimise the effect on strength reduction due to openings.

An experimental study, along with numerical simulations conducted by Broniewicz et al 2023 [4], is focused on failure in the area of the inspection hole in GFRP poles (Glass fibre-reinforced polymer). A full-scale experimental test, including a validation process using a finite element model, was used to investigate the local buckling behaviour of thin-walled GFRP poles in that study. The results indicated that pole failure occurred along the free edges of the inspection hole in all four test poles due to the reduction of the area of the cross-section near the hole (Figure 2a).

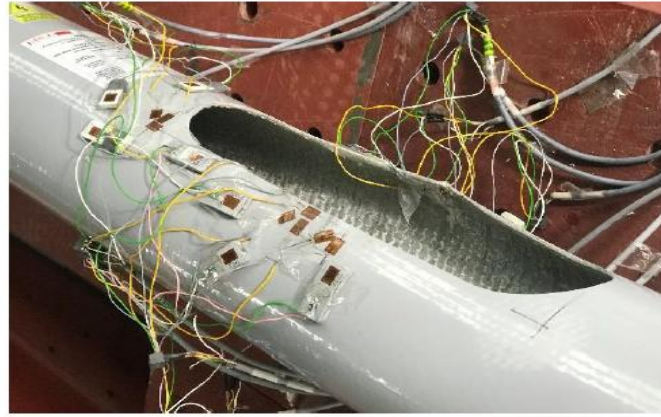


Figure 2a. Local buckling at free edges of opening [4]

According to Nawar et al 2022 [5], in another full-scale experimental study relevant to studying of structural efficiency of tapered GFRP poles, with utility openings revealed that local buckling near the

utility openings is a critical failure scenario (figure 2b). It also indicated that a reinforcing ring applied to this area can significantly improve the poles local buckling capacities.

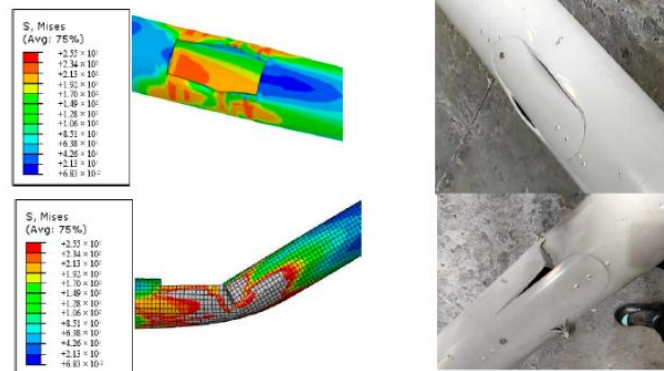


Figure 2b. Local buckling near openings [5]

A study by Khalaf 2017 [6] investigated the bending behaviour of steel circular hollow sections with openings, focusing on how these openings affect the structural performance, conducting a series of experimental tests. The study identified that the ultimate load values were considerably decreased with openings compared to the reference specimen with no openings.

A study conducted by Alsalah et al 2017 [7] investigated the recovery of capacity lost due to

openings in cylindrical shells under compression, focusing on shell structures such as wind turbine towers and silos. Accordingly, it has explored that different stiffening methods that can be applied to recover the reduced capacity. Results revealed that the Width of the cutout is the critical dimension which mostly affects load-bearing capacity. Fabricating an enclosed frame ring along the perimeter of the opening (Figure 3) was the most effective method to recover capacity losses.

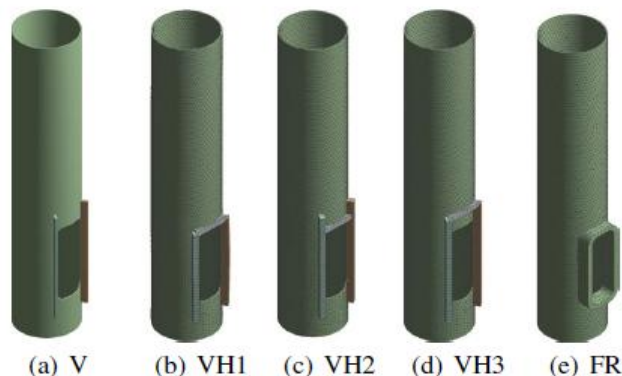


Figure 3. Strengthening of the opening [7]

Research by chao- Li et al 2023 [8] has focused on Buckling Load of Cylindrical Shell with an Inclined through Crack. They have highlighted that buckling capacity of this type of cylindrical shell decrease with length/radius ratio.

Cuong B.H. 2021 [9] discussed about semi-analytical finite strip method buckling behavior of thin-walled circular hollow sections. However, that study has not considered availability of any openings or defects in the section.

Nevertheless, it was noted that research paper on studying buckling behavior of hollow poles is limited in general.

Considering the outcomes of this research, it was decided to focus this study on investigating structural

effects of dodecagon (16 sided) type hollow poles commonly used as smart poles in Sri Lanka. Usually, these poles are commonly produced out of S345 steel and any previous study on this aspect of these poles have not been carried out in local content. Further, as already discussed, provisions of more than one opening is becoming common in present context due to various operational requirements. However, none of these previous studies has focused on these aspects, even though these types of poles would be more susceptible for premature failures due to local buckling. Hence, this study is more focused on structural behavior of poles with dual openings.

2. METHODOLOGY

A systematic approach is adopted in this study to analyse the structural performance of steel hollow poles with utility openings. Smart poles used in the industry are multipurpose structures designed to accommodate various operational and technological needs. These poles are hollow steel sections that have a range of heights from 15m to 35m. Finite element

models were developed for commonly used hollow steel pole designs having two different heights using SAP2000 analytical software. A common design adopted for 20m & 24m smart poles in Sri Lanka was selected in this regard. Basic dimensions and equipment details of these poles are listed in [table 1](#).

Table 1. General details of selected poles

	20m Pole	24m Pole
Bottom Dia.	620mm	650mm
Top Dia.	250mm	250mm
Make of the body	6mm thick steel plate (S345) & Hot dip Galvanized	6mm thick steel plate (S345) & Hot dip Galvanized
Section type	Dodecagon	Dodecagon
Mounted Equipment's	Solar Panel, 9 Antennas, Street light, Digital Screen, CCTV camera	2 Solar Panel, Transmission Antennas, Street light with brackets (2 Nos), Digital LED Screen, CCTV camera

2.1. Effect of the wind direction

Direction of the wind is a critical factor when it is assessing stresses close to openings of a pole. Hence, prior to performing buckling analysis of poles with two openings, identification of critical wind direction is important as performing of buckling analyses for non-critical cases is not really important. Therefore, a series of analyses were performed with different wind directions with poles having no openings, single openings & double openings. Considered wind directional cases are presented in

the [Table 2](#). With the no opening condition, only 00 (1A) wind direction was considered, as there was no effect by changing wind direction under this scenario. In the case of single opening, five different wind direction scenarios were considered. For the double opening case, three different cases listed in the [Table 2](#) were considered as further changes of direction would not cause any additional critical condition. A graphical representation of these considered cases are presented in [figure 4](#).

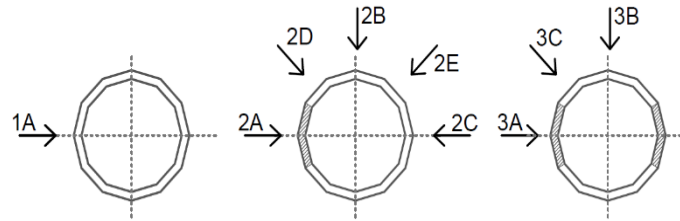


Figure 2. Specimen on digital Rockwell hardness testing machine

Table 1. Mechanical properties of S355 steel [7]

Opening Configuration	Wind direction Considered	
	Scenario No	Angle with respect to horizontal (Degrees)
No Openings	1A	0
With One Opening	2A	0
	2B	90
	2C	180
	2D	45
	2E	225
With Openings on both sides	3A	0
	3B	90
	3C	45

As directional wind analyses were performed to identify the critical wind directional scenario for detailed buckling analysis, It was only considered the 20m dodecagon pole for this analysis (Rationally, It can't expect a different wind directional scenario for 24m pole as it would not depend on the diameter of the pole) . Detailed results for these analyses were presented under results and discussion. As per results, stresses at any place of the pole did not exceed the yield strength of the material under any wind direction with single or double openings. Hence, it can't expect ultimate strength failure in poles under these considered scenarios. According to results, the highest compressive stresses in and around openings under single and double opening cases were reported under wind

direction 2C & 3A, respectively. Therefore, it was decided to consider wind direction 3A for buckling analysis of poles with double openings with different utility opening sizes.

In load application, Partial factors for loads (γ_f) were considered as 1.2 x Dead loads +1.4 x Wind load according to BS 5950 -1 : 2000 [10]. Loads and moments applied on the structure due to equipment were included in the FE model as nodal loads at specific heights at which those are supposed to be installed.

Wind calculation was carried out as per the guidelines of CP3 Chapter V [11]. A basic design wind speed of 33.5 m/s was considered for this analysis.

2.2. Effect of the opening dimensions on local buckling

To assess the effect of opening widths and opening heights on local buckling of poles, it was decided to use 20m & 24m smart poles for the analysis. Accordingly, 12 cases with double openings listed in [table 3](#) was considered. These openings were introduced to two exact opposite sides parallel to the wind direction to simulate the most critical condition for buckling with double openings. In first, width of

the openings were varied from 200mm to 400mm while keeping opening height at 1500mm. Secondly, opening height was increased to 1800mm and width of the opening was again varied from 200mm to 400mm. SAP 2000 models for every case were developed out of thin shell elements with actual dimensional parameters of 20m & 24m poles. It was used the auto meshing option to mesh models

developed for analysis while considering acceptable aspect ratio during meshing.

Table 2. Dimensional parameters of cases considered for buckling analyses

Pole Design	Case No	Opening Width (mm)	Opening Height (mm)
20m Smart Pole	1	200	1500
	2	300	1500
	3	400	1500
	4	200	1800
	5	300	1800
	6	400	1800
24m Smart Pole	7	200	1500
	8	300	1500
	9	400	1500
	10	200	1800
	11	300	1800
	12	400	1800

It was decided to use buckling analysis tool in SAP 2000 for this analysis. However, for verification of accuracy of models & approach, a manual buckling analysis of 20m pole with double openings (having a size of 500mm x1500mm) under 900 wind condition was also performed and compared with results of buckling analysis of SAP 2000. In manual analysis, it was considered that the entire pole segment within height of the opening in the compression side subjected to buckling with the effective height equivalent to the height of opening. Accordingly, the load factor (Load Factor = Buckling load capacity/ Actual Stress) was found as 0.71 by the manual analysis. The load factor reported from SAP 2000 analysis for the same case is 0.80. A reasonable match between reported values can be seen even though results of SAP 2000 value

is slightly high. The assumption of considering the entire segment is subjected to compression as one unit in the manual analysis would be the probable reason for this variation. However, this type of manual verification would be difficult to be performed under wind direction 00 due to complex stress variation in poles. Hence, SAP 2000 buckling analyses were directly used to calculate buckling load factors for 12 cases listed in [table 3](#).

To improve the local buckling capacity in the region where openings are introduced, different improvement techniques are used by manufacturers. To check the effectiveness of these different techniques under double opening condition, 20m & 24m poles (with opening size of 300mm x 1500mm) were reanalysed with different strengthening techniques listed in [table 4](#).

Table 3. Cases considered for effect of the openings

Pole Design	Case No	Opening Width (mm)	Opening Height (mm)
20m Smart Pole	1	200	1500
	2	300	1500
	3	400	1500
	4	200	1800
	5	300	1800

	6	400	1800
24m Smart Pole	7	200	1500
	8	300	1500
	9	400	1500
	10	200	1800
	11	300	1800
	12	400	1800

A graphical representation of those strengthening techniques were presented in [figure 5](#).

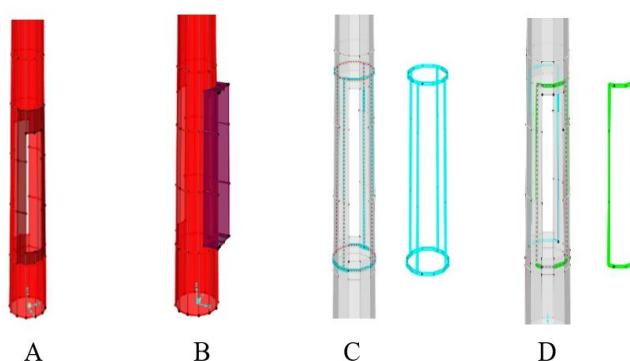


Figure 5. Proposed strengthening arrangements

The power spectral density (PSD) was determined by applying the Fast Fourier Transform (FFT) to the acceleration data, and the PSD vs. frequency was generated in MATLAB Online software. The

dominant frequency in the plot is the natural frequency of the bridge. The PSD vs frequency plots for the locations A, B, C and D are shown in [Figures 5, 6, 7, and 8](#), respectively.

3. RESULTS AND DISCUSSION

3.1. Wind analysis with directional effect

Results of stress analyses performed to check directional effects on stresses in the region of

openings as discussed in section 2.1 are presented in [table 5](#).

Table 4. Maximum Von–Mise’s stress on members

Opening arrangement	Scenario no	Wind direction (Angle in degrees with X axis)	Max. stress in compression side (N/mm ²)
Without opening	1A	0	88.2
One opening	2A	0	88.2
	2B	90	76.2
	2C	180	157.6
	2D	45	85.1
	2E	225	143.5
Openings on both sides	3A	0	184.5
	3B	90	76.2
	3C	45	161.2

As expected, a drastic increase of compressive stresses has been observed with the introduction of openings.

In case of single opening condition, the highest stress of 157.6 N/mm² (Which is 78% higher than the maximum compressive stress of non-opening condition) was reported under 1800 wind direction. However, in the case of two opening condition, the highest stress of 184.5 N/mm² (which is 110% higher than the maximum compressive stress of non-

opening conditions) was reported with 00 wind direction. Loss of material in and around extreme ends with the introduction of openings causing a significant reduction of second moment area of the section under 00 wind condition would be the main reason for this observation. Accordingly, it was identified that this case would be the most critical condition to be considered for buckling analysis to study the effect of opening sizes on buckling performance of poles with double openings.

3.2. Buckling analysis of poles with double openings

To assess the effect of the width of openings & height of the openings, 20m & 24m poles were subjected to buckling analysis with opening sizes

listed in the [table 4](#) with wind 00 direction. Results of these analyses were presented in [table 6](#).

Table 5. STF values on the plate

Opening size (mm)	20m Smart Pole		24m Smart Pole	
	Avg. stress near opening N/mm ²	Buckling Load factor (FE model)	Avg. stress near opening N/mm ²	Buckling Load factor (FE model)
200x1500	97.4	0.741	113.0	1.362
300x1500	135.2	0.513	163.0	0.935
400x1500	182.0	0.384	211.3	0.685
200x1800	98.2	0.713	116.1	1.342
300x1800	139.4	0.510	176.6	0.925
400x1800	184.0	0.382	234.7	0.662

According to results, buckling load factors of 20m pole with all opening sizes are less than 1. However, in case of 24m pole, which is having relatively larger diameter, has reported buckling load factors more than 1 when the width of the openings is 200mm irrespective of height of openings. with 300mm width, buckling load factors are very close to 1 (slightly less than 1) with all heights of openings. Nevertheless, when opening width is increased to 400mm buckling load factors has gone below 0.7 for

both considered heights of openings. To observe percentage reductions of buckling load factor with the increase of the width of opening while keeping opening height at a constant value, percentage reductions of buckling load factors are tabulated in [table 7.1](#) with. Similarly, to study percentage reduction of buckling load factor with the increase of height of openings while keeping width of openings at a constant value, percentage reductions are tabulated in [table 7.2](#).

Table 7.1. Percentage reductions of Buckling Load Factor (Varying opening width while keeping height constant)

Pole height	Variation of opening width (mm)	Opening height (mm)	
		1500	1800
20m Pole	200 - 300	30.70%	28.50%
	300 - 400	25.20%	25.10%
24m Pole	200 - 300	31.40%	31.10%
	300 - 400	26.70%	28.40%

Table 6.2. Percentage reductions of Buckling Load Factor (Varying opening height while keeping width constant)

	Variation of opening height (mm)	Opening Width (mm)		
		200	300	400
20m Pole	1500 - 1800	3.50%	0.60%	0.60%
24m Pole	1500 - 1800	1.50%	1.10%	3.30%

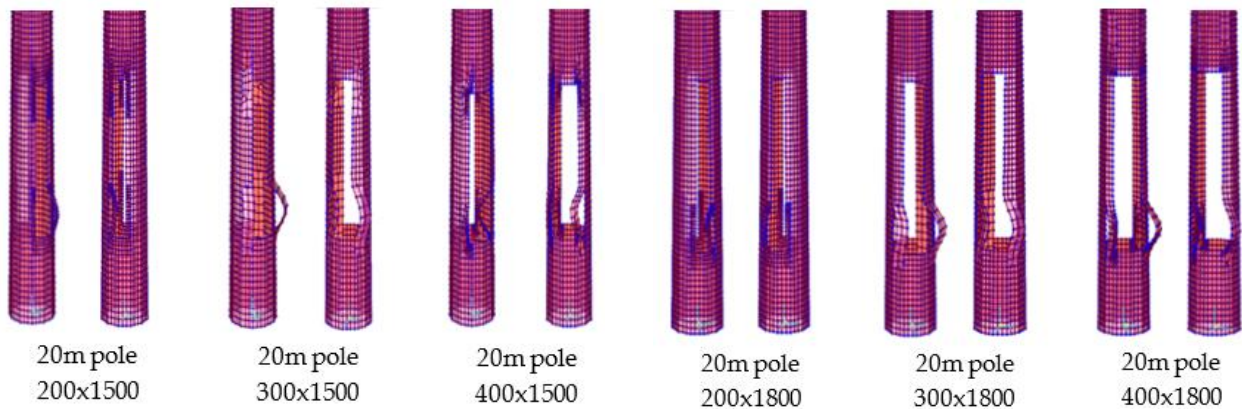


Figure 6a. Buckling patterns of each case of 20m pole

According to these patterns it is clear that buckling has taken place close to bottom of openings where compressive stresses are maximum.

Additionally, it was observed that the buckling behavior of the FE models of these smart pole designs was close to the buckling patterns demonstrated in the previous experimental studies.

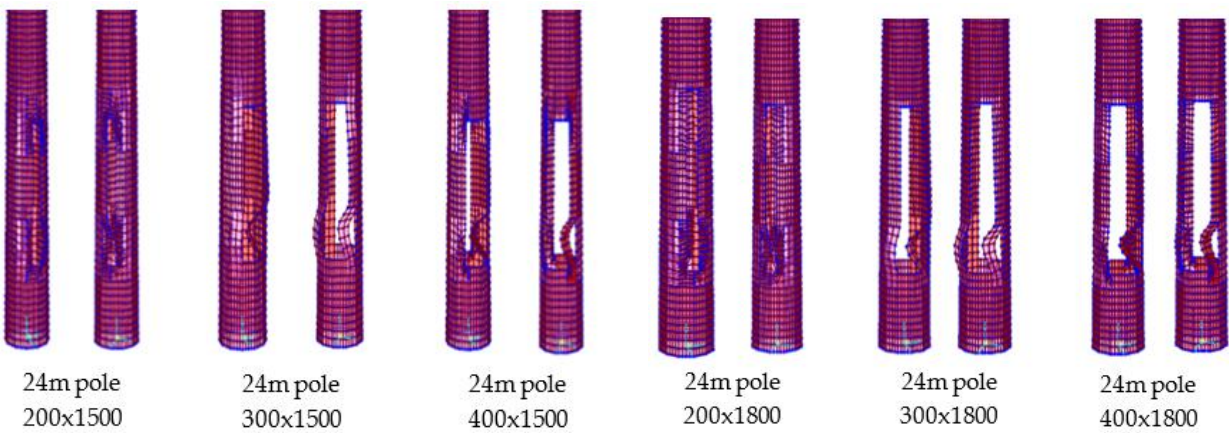


Figure 6b. Buckling patterns of each case of 24m pole

As expected, a drastic increase of compressive stresses has been observed with the introduction of openings. In the bending tests carried out for GFRP poles [4], the test results showed similar pattern of localized buckling along the free edges of the inspection hole (Figure 2a). A similar pattern of buckling (Figure 2b) has been reported in another bending test conducted on lighting poles subjected to lateral loads [5]. The drastic reduction of bearing area between openings with the increase of widths of openings causing high stresses concentrations between

openings would be the probable reasons for drastic reductions of buckling load factors reported in table 7.1. Increase of opening height would mainly effect on buckling heights when the width of the openings is constant, and hence, increment of height of openings would not cause drastic reductions of buckling factors as high as in the previous case. In summary, it is evident that introduction of double openings for this type poles drastically affecting on buckling capacities of poles and increase of width of openings is more critical than the increase of height.

3.3. Effect of strengthening arrangements for buckling capacity

As already discussed, buckling analysis for 20m & 24m poles having double openings (with the size of 300mm x 1500mm) with different strengthening arrangements listed in the [table 8](#) were performed. Buckling load factors reported for all considered cases are presented in [table 8](#).

As it can be observed in [table 8](#), all considered techniques were able to deliver buckling load factor greater than 1, ensuring acceptable buckling load capacities. In case of 24m pole, the highest buckling load factor was reported with the provision of steel pole boxing thickness of 8mm (B2 type). The second

highest buckling load factor was reported with same type having thickness of 6mm (B1 type). However, in case of 20m pole, the highest buckling load factor was reported in the case where it has provided 25mm x 25mm square around the opening (C1 type). Nevertheless, provision of steel boxes has also provided an acceptable improvement in buckling resistance as it can be observed in [table 8](#). The reason for variation of best strengthening technique for 20m & 24m poles cannot be clearly identified from these results and further study on this aspect is recommended.

Table 8. Results of buckling analysis after different strengthening arrangements

No	Strengthening arrangement ($F_y = 345 \text{ N/mm}^2$ steel members)	Buckling Load Factor (FE model)	
		20m Pole (300x1500 mm opening)	24m Pole (300x1500 mm opening)
A	Increased Plate thickness (8mm)	1.007	Not applicable
B1	Steel Plate Box around the opening (6mm)	1.408	3.341
B2	Steel Plate Box around the opening (8mm)	2.005	3.665
C1	Steel Ring Type 1 (25mm x25mm square steel bar)	3.398	3.316
C2	Steel Ring Type 1 (20mm x20mm square steel bar)	1.9	2.143
D1	Steel Ring Type 2 (25mm x25mm square steel bar)	2.465	2.401
D2	Steel Ring Type 2 (20mm x20mm square steel bar)	1.813	1.974

[Figure 7a](#) and [figure 7b](#) show the buckling patterns of certain selected cases with different strengthening approaches. It is evident that buckling patterns have changed with strengthening of edges of openings, as

it is visible in [figure 6a](#) and [figure 6b](#). It also justifies the improvement of buckling load factors with strengthening.

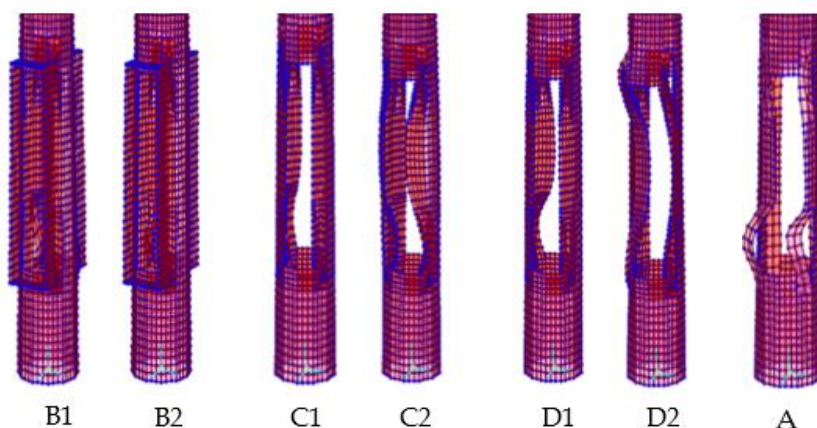


Figure 7a. Buckling patterns after strengthening of 20m pole (300 x 1500mm opening)

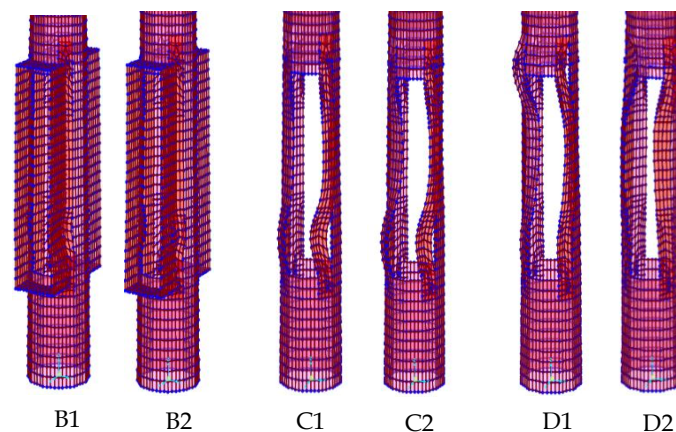


Figure 7b. Buckling patterns after strengthening of 24m pole (300 x 1500mm opening)

4. CONCLUSION

Main objective of this study was analyzing the effect of introducing service openings (especially dual openings) on material and buckling strengths of utility poles. As per results of the study, drastic increase of stresses around openings was reported with the introduction of openings. However, those stresses were below yielding strength of the material used to fabricate these poles in each case.

Secondly, possibility of occurring local buckling in the region of openings was studied. According to the results, buckling capacity was seriously affected by introduction of openings, especially in 20m pole. Even in 24m pole, exceedance of buckling capacity was noted with increase of width of the opening. Also, it was noted that the increase of width was more severely affecting on buckling capacity than height of openings. This would be due to the

reduction of bearing area with the increase of width of openings causing direct increment of stresses in the region.

Nevertheless, introduction of some form of strengthening around openings was ensured the achievement of required buckling capacity in all the cases considered in this study. Especially, provision of box type strengthening around the opening (which is the most commonly used strengthening technique in the industry especially in local context), has found to be effective against controlling local buckling of poles with dual openings.

However, further studies on this aspect of utility poles are recommended as this would be on critical failure scenario for this type of poles and lack of research on studies on this matter.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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